

METHOD FOR MONITORING THE TEMPERATURE OF A BIOCHEMICAL
REACTION

The present invention relates to a method of carrying out an
amplification reaction and in particular a polymerase chain
5 reaction (PCR) using an internal temperature control mechanism.

A common problem in biochemical reactions, in particular
miniaturised biochemical reactions is controlling the
temperature. Invasive temperature probes add to the thermal
10 mass of the sample and increase time constraints associated
with heating and cooling. A particular example where such a
problem occurs is with minaturised amplification reactions such
as the PCR reaction. In this reaction, cycling between various
accurate temperatures is an essential element. In outline, the
15 procedure consists of the following steps, repeated cyclically.
Denaturation : A mixture containing the PCR reagents (including
the DNA to be copied, the individual nucleotide bases
(A,T,G,C), suitable primers and polymerase enzyme) are heated
to a predetermined temperature to separate the two strands of
20 the target DNA.

Annealing : The mixture is then cooled to another predetermined
temperature and the primers locate their complementary
sequences on the DNA strands and bind to them.

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Extension : The mixture is heated again to a further
predetermined temperature. The polymerase enzyme (acting as a
catalyst) joins the individual nucleotide bases to the end of
the primer to form a new strand of DNA which is complementary
30 to the sequence of the target DNA, the two strands being bound
together.

Any interference with the reaching the predetermined
temperatures as a result of the temperature measurement can
35 present a significant problem in terms of the success of the
amplification reaction.

The applicants have found a way in which the temperature present in a biochemical reaction can be monitored without the need for the application of temperature probes.

- 5 According to the present invention there is provided a method of monitoring the temperature of a biochemical reaction, said method comprising effecting the reaction in the presence of a fluorescently labelled temperature probe DNA sequence which comprises a double stranded region which denatures at a
10 predetermined temperature, the fluorescent label or said temperature probe sequence being arranged so that the nature of the fluorescence changes at the point at which denaturation of the said region takes place; and monitoring fluorescence from said reaction mixture so as to determine when the said
15 predetermined temperature has been reached.

- The labelled temperature probe DNA sequence added to the reaction mixture in the method acts as a temperature probe allowing the temperature of the reaction to be accurately set
20 without requiring external temperature probes.

- The temperature probe DNA sequence may comprise a double stranded DNA sequence, or it may be in the form of a single nucleic acid strand, end regions of which hybridise together so
25 as to form a loop or "hairpin" structure.

- Suitable fluorescent labels include intercalating dyes, which are interposed between the strands of a double stranded region of a DNA sequence. When the double stranded DNA region
30 containing the intercalating dye reaches the predetermined temperature, it will be denatured, thus releasing the intercalating dye present between the strands. At this point the fluorescence from the mixture will reduce significantly, giving a readable signal.

- 35 *Brief Description of the Drawings*
The process using a double stranded DNA sequence as a temperature probe is illustrated diagrammatically in Figure 1 hereinafter.

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When intercalating dye (2) is added to a solution of double stranded DNA (1), it becomes interposed between the strands. The concentration of the dye (2) in this way produces a recognisable signal. On heating of the DNA so that it is
5 denatured, dye is released and this event can be witnessed. Cooling to a temperature at which the said sequence will anneal again results in the intercalating dye becoming again trapped between the strands (see Figure 1).

- 10 Suitable intercalating dyes include SYBRGreen™, SYBRGold™ and ethidium bromide or other commercially available dyes.

Alternatively, the fluorescent label used in the method of the invention may utilise fluorescence resonance transfer (FRET) as
15 the basis of the signal. These labels utilise the transfer of energy between a reporter and a quencher molecule. The reporter molecule is excited with a specific wavelength of light for which it will normally exhibit a fluorescence emission wavelength. The quencher molecule is also excited at this
20 wavelength such that it can accept the emission energy of the reporter molecule by resonance transfer when they are in close proximity (e.g. on the same, or a neighbouring molecule). The basis of FRET detection is to monitor the changes at reporter and quencher emission wavelengths.

- 25 For use in the context of the present invention, the DNA sequence used as a temperature probe can be provided with a reporter and a quencher molecule, arranged so that the hybridisation of the strands alters the spatial relationship
30 between the quencher and reporter molecules. Examples of such arrangements are illustrated in Figure 2 and Figure 3.

Figure 2 illustrates an Example where the temperature probe sequence is a single stranded "hairpin" type sequence (3),
35 where the end portions hybridise together. A reporter molecule (4) is attached in the region of either the 5' or the 3' end of the sequence and a quencher molecule (5) is attached at the opposite end such that they are brought into close proximity

when the sequence is in the form of the loop. In this arrangement, FRET occurs and so fluorescent signal from the reporter molecule is reduced whilst the signal from the quencher (5) molecule is enhanced.

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On denaturation however, the opposed end regions of the sequence separate so that the reporter and quencher molecules become spaced and so FRET no longer occurs. This changes the signals from the respective molecules and so this event can be
10 detected.

Another arrangement is illustrated in Figure 3. In this case, the reporter (4) and quencher molecules (5) are located on different strands (6,7 respectively) of a DNA temperature probe
15 sequence and are located such that on hybridisation of the strands, they are brought into close proximity to each other so that FRET can occur.

Yet a further embodiment is illustrated in Figure 4. In this case, an intercalating dye (2) is used as an element of the
20 FRET system. A quencher molecule (5) which can absorb radiation from the dye may be arranged on a strand of the temperature probe sequence such that it can absorb radiation from dye which is close proximity to on hybridisation of the
25 strands. When the temperature probe sequence reaches a temperature at which it is denatured, the dye (2) is dispersed and so the signal from the quencher molecule (5) changes.

This embodiment is advantageous in that only a single label
30 need be applied to the temperature probe sequence. Single labelled sequences of this type are more economical to produce.

In yet a further embodiment (Figure 5), the reporter (4) and quencher (5) molecules are positioned on two oligonucleotide
35 strands (9 and 10 respectively) which do not hybridise together. They are however designed so that in use, they hybridise to a DNA sequence present in the reaction mixture, which may be a plasmid (11), such that the reporter (4) and

quencher (5) are brought into close proximity and FRET can occur between them, giving a recognisable signal.

The DNA sequence to which they bind may be part of the reaction system, for example where the reaction being monitored is a PCR reaction wherein the DNA sequence comprises or is part of the amplification target sequence. Alternatively, the sequences may be added to the reaction in order to provide the basis for the temperature probe of the invention.

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The temperature probe sequence of the invention may be designed so that it denatures at any desired predetermined temperature. For example, the denaturation temperature of a sequence depends to some extent on its length. Longer sequences will denature or melt at higher temperatures. Furthermore, it is known that the bases C and G bind together more strongly than A and T. Therefore, the greater the higher the content of the bases G and C contained within a sequence, the higher the melting point of the sequence will be. This feature is illustrated in Figure 5 which shows the melting temperature of a DNA sequence plotted against the percentage of and GC base pairs which are present within in. Thus, by adjusting the GC content, the temperature probe sequence may be designed so that, if desired, it also has a predetermined length.

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The method of the invention is particularly applicable for use in amplification reactions such as the polymerase chain reaction (PCR). In this case, the temperature probe sequence of the invention is introduced into the reaction vessel. Suitably the temperature probe sequence is designed such that it generates a detectable signal when it reaches the optimum annealing temperature of the target DNA sequence as this is intermediate temperature is most difficult to set accurately in practice. However, more than one such temperature probe sequence may be added and arranged to provide appropriate and preferably different signals when the predetermined extension and/or denaturation temperatures have been reached.

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The invention will now be particularly described by way of example with reference to the accompanying diagrammatic drawings in which:

- 5 Figure 1 illustrates the formation and use of a labelled temperature probe sequence for use in the method of the invention;

- 10 Figures 2 to 5 represent alternative embodiments of the labelled temperature probe sequences of the invention and the denaturation thereof;

Figure 6 illustrates a construct used in the examples hereinafter; and

- 15 Figure 7 shows the melting temperature of plasmid constructs and inserts as measured using the method of the invention, as a function of the percentage GC content of the construct, where the lighter line represents the oligonucleotides and the darker line represents the -47/-48 amplicon from constructs.
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Example 1

- Oligonucleotides, 60 base pairs in length, were designed by randomly removing the letters G, A, T and C from a paper bag.
- 25 Complementary pairs of the thus formed random oligonucleotides were mixed together at a final concentration of 1 μ M and 1:40,000 dilution of SYBRGreenTM reference dye. The mixtures were then loaded into LightCyclerTM tubes and the temperature slowly raised from 40°C to 110°C. The fluorescence at 520nm was
- 30 measured and was seen to drop off as the temperature was raised. The differential of fluorescence was used to determine the peak rate of change (i.e. drop) which corresponds to the strands melting. 20%, 40%, 50% 60% and 80% GC oligos were used in different experiments. The results, expressed as a graph of
- 35 melting temperature vs GC content is shown as Figure 7.

Example 2

The different GC duplexes used in Example 1 were cloned into the vector polylinker of pUC19 plasmid as illustrated in Figure 6. This plasmid was subjected to a polymerase chain reaction using vector primer sites, the -47 and -48 sequencing primer sites. The PCR reaction contained 1:40,000 dilution of SYBRGold™ reference dye. After PCR on the LightCycler™, the products were melted off as described in Example 1. The melting temperature of the different amplicons vs the GC content is shown on the graph (Figure 7).